ECOLOGICAL IMPACTS OF RECREATIONAL VEHICLE USE ON SALTMARSHES OF THE GEORGES RIVER, SYDNEY

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ABSTRACT

The unauthorised use of recreational vehicles (trail bikes, BMX, 4WDs, mountain bikes) is a major threat to many saltmarsh communities of the Georges River, Sydney. Analysis of historical aerial photographs was undertaken to quantify the saltmarsh areas damaged by vehicle use and a field study conducted to assess the associated ecological impacts. The field study involved a comparison of vegetation, soil and invertebrate fauna parameters between undisturbed, low and high track density areas of four communities dominated by the low-growing chenopod *Sarcocornia quinqueflora* and two communities dominated by the taller rush *Juncus kraussii*.

Aerial photo analysis showed that over 21000m^2 of saltmarsh has been directly impacted by vehicle use along the Georges River, with observations of vehicle use suggesting a continuing increase to this area. The field study showed that vegetation cover, soil compaction, soil moisture, and mollusc and crab distributions were all adversely affected by vehicle use. In *Sarcocornia* communities the impacts were most severe in areas of high track density, though single track areas also showed significant effects. *Juncus* communities generally showed less damage, due in part to morphological characteristics of the dominant plant species. In both community types vehicle ruts and excavations were prone to waterlogging, could alter vegetation composition and facilitate the breeding of mosquitoes and spread of mangroves. Recommendations are made for the control of vehicle use and restoration of damaged saltmarshes.

INTRODUCTION

Coastal saltmarshes are intertidal ecosystems vegetated by herbs, grasses, rushes and small shrubs which provide a permanent or temporary habitat for a range of animals. Saltmarshes also have importance as a natural buffer to coastal waterways and as significant nurseries for estuarine fauna. Along the New South Wales coast, however, ‘reclamation’ and development have claimed many saltmarshes, whilst most of those remaining are experiencing a rapid landward advance of mangroves (Saintilan & Williams 1999). In more recent years, the unauthorised use of recreational vehicles (trail bikes, four wheel drives, BMX and mountain bikes) has become one of the most rapidly escalating and serious forms of human disturbance to saltmarshes. Anecdotal evidence suggests that large areas of some marshes of the Georges River have been lost due to the use of recreational vehicles (Adam 2002). Evidence of vehicle use has also been observed in European (Adam, 1990) and North American saltmarshes (Prindiville-Gaines & Ryan 1988). However, very few studies have been conducted on the ecological impacts of recreational vehicles in saltmarshes. The vulnerability of saltmarsh ecosystems to physical disturbance, conversely, is widely documented. Andersen (1995) found human trampling to cause significant reductions in the total number and cover of vascular plant species in a Danish saltmarsh, while amphibious management vehicles have been seen to reduce plant biomass and stem height in a North American marsh (Hannaford & Resh 1999). In Australia, studies of the physical impacts of cattle grazing (Zedler *et al.* 1995) and mosquito control techniques (Breitfuss *et al.* 2004) have linked hydrological alterations with floristic composition, propagule transport and invertebrate populations.

The ecological impacts of recreational vehicle use have also been well studied, though almost exclusively in terrestrial environments. Studies in coastal sand dune (Liddle & Greig-Smith 1975a, b), meadow and forest (Weaver & Dale 1978), grassland (Chappell *et al.* 1971), rangeland (Payne *et al.* 1983) and desert (Bury *et al.* 1977) ecosystems have furthered our knowledge of this activity on a variety of floristic, faunal and soil types.

Vegetation changes are generally the most visible impacts of vehicle use in natural areas. While plant cover decreases with increased vehicle passage (as was the case in all studies reviewed), it has long been understood that plant morphology and biomass influence each plant’s response and resistance to damage (Bates 1935). Studies by Sun and Liddle (1993a, b) have shown stem flexibility, leaf strength and number of tillers as the most important features of trampling resistant Australian grass species.

Vegetation composition can also be altered by vehicle use. For example, tyres have been shown to act as vectors for seed transport and the spread of exotic species in some ecosystems (Lonsdale & Lane 1992). Similarly, increases in ground litter resulting from trampling may increase nutrient levels and assist the emergence of new plants (e.g. Chappell *et al.* 1971).

Consideration of soil impacts associated with vehicle use has focused largely on measurements of soil compaction (e.g. Chappell *et al.* 1971; Weaver & Dale 1978; de Gouvenain 1996). Increases in soil bulk density and resistance to penetration can restrict plant root growth (Russell, 1973; cited in Liddle, 1997), reduce root aeration and nutrient availability (de Gouvenain 1996) and prevent the establishment of plant seedlings (Blom 1977). In saltmarshes, soil surface microtopography may also be particularly susceptible to alterations as waterlogged soils have been found to experience far greater structural damage than freely drained soils (Bellamy *et al.* 1971).

Although receiving little attention, it has been acknowledged that vehicle use can significantly impact upon soil dwelling fauna (Chappell *et al.* 1971; Wolcott & Wolcott 1984). This is of particular importance in saltmarshes, where soil invertebrates (especially molluscs and crabs) perform essential ecological processes. Although few studies have been carried out on saltmarsh species, studies in other estuarine habitats have shown crab (Kaly *et al.* 1997) and mollusc populations (Uhrin & Holmquist 2003) to be adversely affected by physical disturbances.

Clearly, there is a shortage of scientific knowledge on the impacts of vehicle in saltmarsh ecosystems. This study aims to address this by: i) quantifying the areas of saltmarsh lost along the Georges River due to unauthorised vehicle use; ii) determining the differences in habitat characteristics of undisturbed, low and high impact areas; and iii) comparing the response of *Sarcocornia* and *Juncus* dominated saltmarsh communities.

METHODS

Study sites

The Georges River is the largest estuary of southern Sydney, New South Wales (Figure 1). It contains several, mostly small, remnant saltmarsh communities. West *et al.* (1985) estimated the area of saltmarsh in the Georges River to be 0.247km^2, however, this value is likely to have decreased considerably since. The saltmarsh soils are generally dominated by large grain sands, though loam and clay soils and peat are present in some areas.

Evidence of unauthorised vehicle use was observed at eight saltmarsh communities throughout the river: three communities at Sylvania Waters (SW1, SW2, SW3), two at Still Ck (SC1, SC2), and one each at Mill Creek (MC), Moon Bay (MB) and Sand Point (SP).

Aerial Photo Analysis

Aerial photos from 1966, 1994 and 1998 were analysed to determine the history of vehicle use on study sites and identify the extent of saltmarsh decline due to this activity. The area of the whole saltmarsh, natural unvegetated areas and track areas were quantified at each site using a grid count method. Areas of interspersed mangroves encircled by saltmarsh vegetation were included in analysis, whilst closed mangrove forest areas with no visible saltmarsh species were not.

Field Study

Quadrat Study

In order to determine the impacts of vehicle use on saltmarsh vegetation, fauna and soil properties, quadrats were situated in undisturbed ('control'), low track* density (showing evidence of a single track) and high track density (evidenced by more than one track) areas at SW1, SW2, MC, SC1 (*Sarcocornia* communities), SW3 and SC2 (*Juncus* communities) between July and September, 2004. Sampling was undertaken when marshes were not inundated by the tide (i.e. on low tides or during neap tides) and no sampling occurred within 72h after recorded rainfall events.

Five randomly located blocks (each containing a high (H), low (L) and control (C) quadrat) were established within the historically vegetated areas of each community. Quadrats were 1.0m x 0.5m placed lengthwise along track areas and along an identical orientation in control areas.

Within each quadrat, the cover of each plant species, plant litter and algae were measured using the Domin-Krajina scale (Muller-Dombois & Ellenberg 1974). Plant seedlings were counted; inhabited snail shells were identified and counted and the number of 'maintained' crab burrows (identified following Breitfuss 2003) was also recorded.

Soil texture was determined using standard field techniques (McDonald 1994) with an additional class of 'organic' soils for peat substrates which have very little or no mineral matter.

Soil compaction was determined in the field with the average of five penetrometer measurements (following Malcolm, 1964), while a soil core was taken for laboratory measurement of bulk density, soil moisture content and soil Electrical Conductivity (EC).

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* a distinction is made between a vehicle 'pass' and a 'track' – a single track may be passed several times by a vehicle, although track density generally increases with more passes.

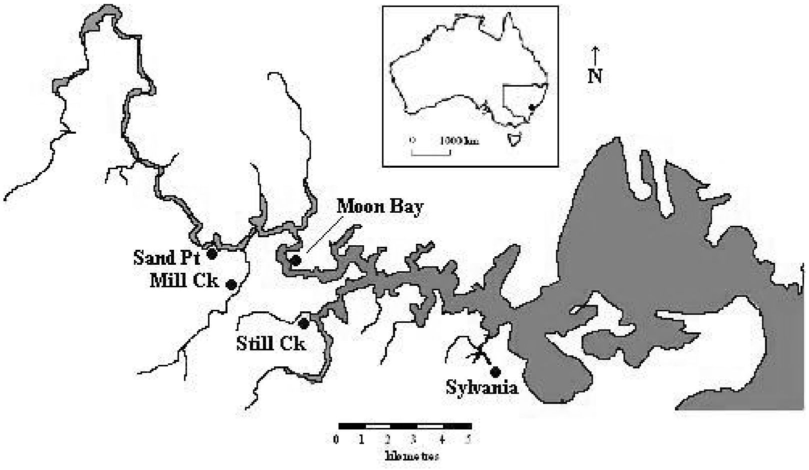

Figure 1: Study sites along the Georges River, New South Wales.

Data Analysis

Quadrat data were separated according to community type (*Sarcocornia* or *Juncus*) and then track density level (C, L, H). Three separate multiway factorial ANOVAs were carried out for each variable of a community type to test for differences between each level of track density.

RESULTS

Aerial Photo Analysis

Aerial photo analysis showed that by 1998 over 21000m^2 of saltmarsh had been directly impacted by vehicle activity (Table 1). With the exception of Sand Pt, all sites showed marked increases in track area between 1994 and 1998, by which time all non-track bare areas were covered by tracks. Historically, the formation of track networks appears to have extended out from naturally bare areas (witnessed at Moon Bay, Mill Ck and SW1). Recent field observations suggest that the extent of damage to some marshes – most notably Still Ck and Mill Ck – has increased considerably since 1998.

Quadrat Study

Vegetation

In both the *Sarcocornia* and *Juncus* communities total vegetation cover (and dominant species cover) decreased significantly with increasing disturbance level (Figure 2a). *S. quinqueflora* seedlings were found in great number in some high (max = 111) and low (max = 98) disturbance areas of the *Sarcocornia* communities, often growing in the ruts created by vehicles. One high disturbance quadrat from the *Juncus* communities also had 10 *S. quinqueflora* seedlings growing in a tyre rut. In both communities however, most quadrats did not contain seedlings and overall differences were not statistically significant.

Although mean litter cover was similar in undisturbed *Sarcocornia* and *Juncus* quadrats, their responses to levels of disturbance varied (Figure 2b). Cover was highest in single track areas of the *Sarcocornia* communities and greatest in high disturbance areas of the *Juncus* communities.

Table 1: Results of aerial photo analysis – areas damaged by vehicle use.

SITE	1966 Track Area (m^2)	%	1994 Track Area (m^2)	%	1998 Track Area (m^2)	%
Sylvania 1	0	0	672	20.4	1,082	38.0
Sylvania 2	0	0	203	7.2	1,001	33.8
Sylvania 3	0	0	0	0	476	41.4
Still Ck	0	0	1,813	6.9	5,007	22.4
Mill Ck	0	0	0	0	1,453	6.2
Moon Bay	0	0	4,094	31.6	4,766	38.9
Sand Pt	2,157	5.3	8,563	29.2	7,418	28.0
TOTAL	2,157	1.5	15,344	15.6	21,203	23.2

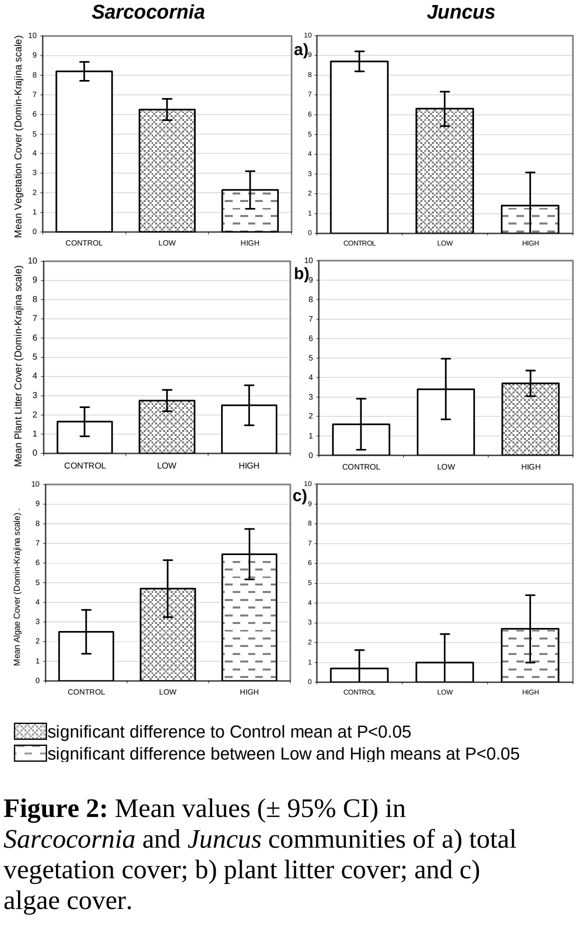

Figure 2: Mean values (± 95% CI) in *Sarcocornia* and *Juncus* communities of a) total vegetation cover; b) plant litter cover; and c) algae cover.

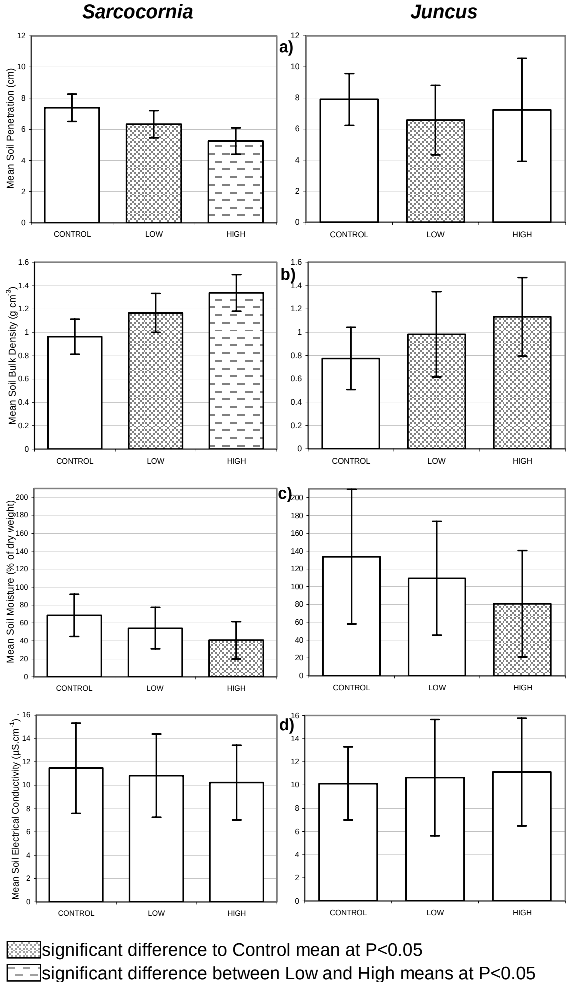

Figure 3: Mean soil values (± 95% CI) in *Sarcocornia* and *Juncus* communities of a) penetration depth; b) bulk density; c) moisture content; and d) electrical conductivity.

Ground covering algae was more prominent in the *Sarcocornia* communities than *Juncus* (Figure 2c). In the *Sarcocornia* marshes particularly, algae often formed thin mats (generally <1cm thick) across bare ground, in some cases moulding to the shape of tyre ruts.

<u>Soil</u>

Soil compaction (as measured by both penetration depth and bulk density) increased significantly with each increase in disturbance level in the *Sarcocornia* communities (Figure 3a, b). In the *Juncus* communities bulk densities were higher than the control mean in both high (P = 0.001) and low (P = 0.020) track areas but the difference between these disturbed areas was not significant (P = 0.103). Also, penetration depth was significantly shallower than the control (mean = 7.91cm) in low track areas (mean = 6.58cm) but not in high track areas (mean = 7.23cm).

Overall, mean soil moisture content was much higher and more variable in *Juncus* than *Sarcocornia* communities (Figure 3c). However a similar trend existed in both community types – i.e. only areas of high track density had significantly lower moisture contents than the control.

Soil conductivity showed no significant relationship with track density in either community type (Figure 3d).

Figures 4 to 6 show examples of the size of wheel ruts created by different vehicles in various soil types. Ruts were more likely to form and were deeper in wet and moist soils, while rut depth increased with vehicle size. Figure 6 shows that ruts as deep as 69mm could form from a single pass of a large vehicle over moist soil.

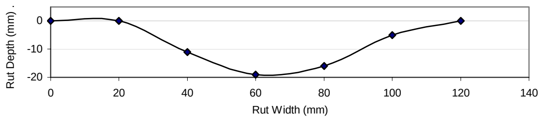

Figure 4: BMX rut in moist sandy soil.

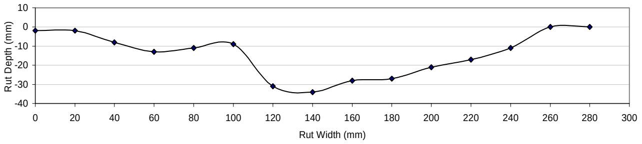

Figure 5: Trail bike rut in moist sandy soil.

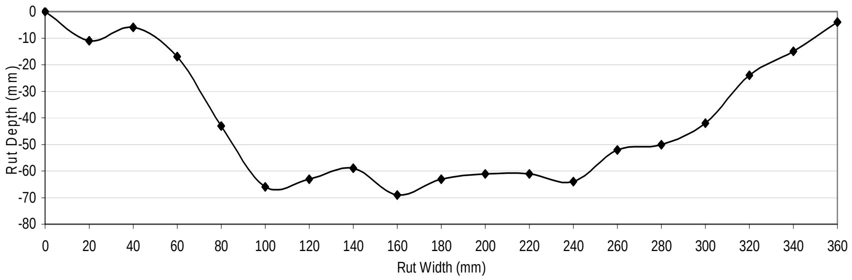

Figure 6: 4WD rut in moist sandy soil.

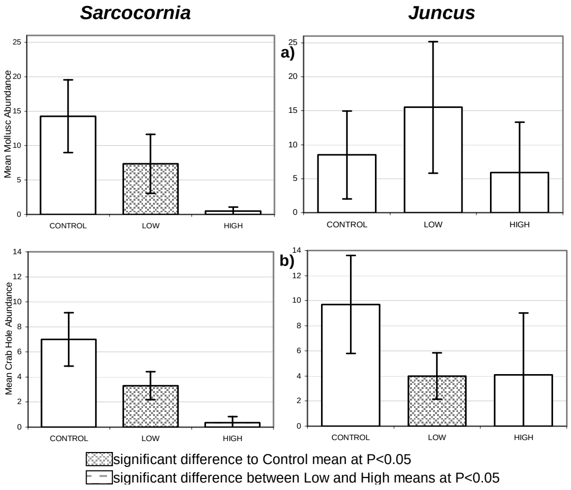

Figure 7: Mean abundances (± 95% CI) in *Sarcocornia* and *Juncus* communities of a) molluscs; and b) crab holes

Fauna

In *Sarcocornia* communities, maintained crab burrow and living mollusc abundances decreased significantly with increases in track density (Figure 7a, b). Notably, no fauna were recorded at all in high disturbance areas of SW1 and SC1 – sites which were observed to have the greatest vehicle use.

In the *Juncus* communities total mollusc abundance was greatest in areas of low track density, but lowest in high track density areas. Whilst this trend was not statistically significant for total mollusc abundance, it was significant for *Ophicardelus ornata* – one of the more common species sampled. Crab burrow abundance in *Juncus* communities was lowest in areas of low track density with significantly fewer than in undisturbed areas (P = 0.011).

Transects

Figures 8 and 9 show the results of transects carried out in *Sarcocornia* and *Juncus* communities at Sylvania Waters. Invertebrate populations were visibly reduced not only in the track areas of the *Sarcocornia* community, but several metres either side of the tracks. Fauna appeared far more resilient surrounding the tracks through the taller, more protected *Juncus* communities. The emergence of mangroves alongside track areas in the *Juncus* community is of particular importance, however, as *Avicennia marina* is not commonly found in the higher *Juncus* communities. Soil penetrability was lowest across major track areas in both transects and generally decreased across single tracks as well.

DISCUSSION

Recreational vehicle use has caused extensive and increasing damage to many of the saltmarshes of the Georges River, with over one-third of the area of most small marshes and significant areas within some larger marshes being severely impacted. Although extensive, the areas reported here are likely to be underestimates - due to limitations of photograph scale. Consequently only disturbed areas of considerable width could be identified - so areas of single and thin tracks may not have been included. Importantly, aerial photo analysis and ground observations also showed that bare, unvegetated areas – whether natural ‘rotten spots’ or previously reclaimed areas - play an important role in attracting initial vehicle use. Therefore, urban saltmarshes with such bare areas are likely to be at particular risk of attracting future vehicle use.

Structural modifications to saltmarshes

Vehicle use can significantly alter the structure and microtopography of saltmarsh surfaces. Vehicle passage, especially across wet or moist soils can create deep ruts which modify local drainage networks and may become waterlogged after tidal inundation or rainfall. Observations showed that in some areas rising tides first entered the saltmarsh via track ruts and depressions,

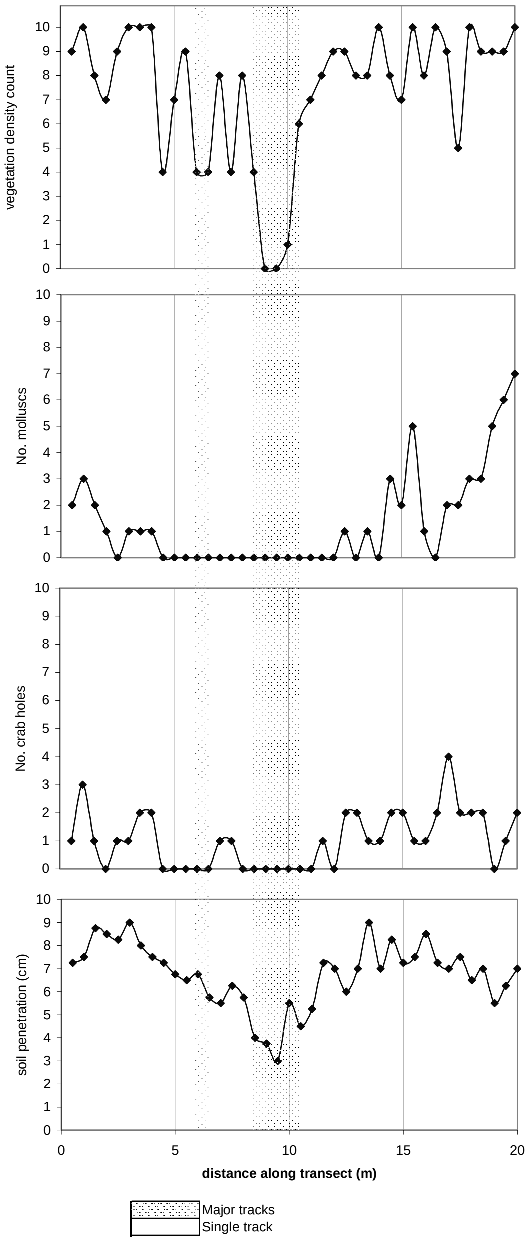

Figure 8: SW1 (*Sarcocornia*) transect

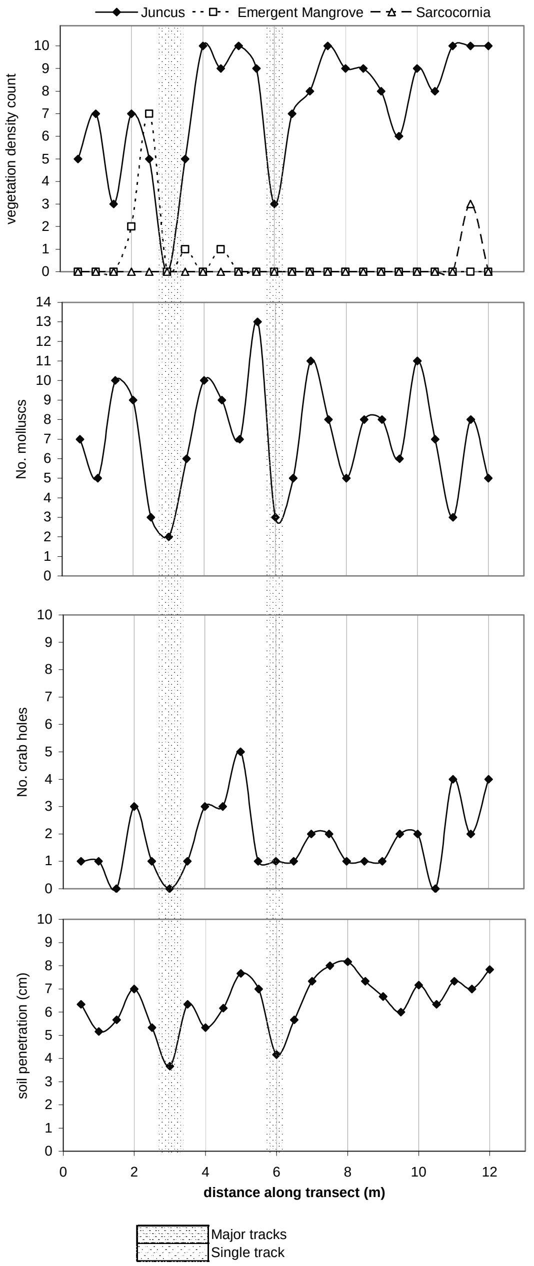

Figure 9: SW3 (*Juncus*) transect

whilst deep ruts perpendicular to the tidal movement often intercepted receding waters (see Figure 10). At many sites microtopography was also altered by the creation of jumps, and excavations from which jumps were built. Many of these excavations became waterlogged pools. Along with waterlogged ruts, these pools may facilitate mosquito breeding, which in itself can have very important health and management implications.

Figure 10: Pooling of water in trail bike ruts at Still Creek

Ecological Impacts of Vehicle Use

The most obvious ecological impact of vehicle use on saltmarshes is a major reduction in vegetation cover. Areas of high track density were usually completely devoid of vegetation in both the *Sarcocornia* and *Juncus* communities, while single track areas also showed significant reductions in comparison to undisturbed areas. Observations suggest that *S. quinqueflora* could be killed by a single pass of a motorised vehicle, or several by a BMX or mountain bike. This is consistent with the results of Hannaford and Resh (1999) who found the morphologically similar species *Salicornia virginica* incurred significant reductions in stem biomass and height with just two passes of slow moving, 'tracked' amphibious vehicles. *J. kraussii* appears to be slightly more tolerant than *S. quinqueflora*, with initial passage by a trail bike pushing culms of the rush towards a horizontal position, but not necessarily causing their detachment. Thus, after an initial pass *J. kraussii* culms (mostly when attached but also as detached 'litter') often provided a protective layer above the soil surface.

Importantly, this study showed no evidence of exotic plants being introduced into saltmarshes by vehicle use. However, it is likely that exotic saltmarsh species such as *Juncus acutus* – which has displaced the native *J. kraussii* in several saltmarshes of the Georges River – may be introduced by vehicles in the future.

Native vegetation composition, however, was altered by vehicles impacts – particularly through modifications to microtopography and local hydrology. The occasional increase in presence of *Sporobolus virginicus* and *Sarcocornia quinqueflora* along the borders of some track areas in *Juncus* communities suggests vehicle related depressions may promote the growth of lower marsh species. Zedler *et al.* (1995) reported a similar consequence in the waterlogging of cattle hoofprints in New South Wales saltmarshes. However, it is also likely that the opening of the *Juncus* canopy may have also influenced alterations to composition. Other plants, such as *Suaeda australis* (which increased slightly in track areas of *Sarcocornia* communities) may have increased their distribution due to their success in areas of physical disturbances (see Adam *et al.* 1988) rather than changes to hydrological conditions.

Perhaps the most important composition change associated with vehicle use is the apparent spread of the mangrove *Avicennia marina*. The expansion of this species into saltmarsh area has been identified as a major threat to the saltmarshes of the Georges River and historically has occurred most rapidly in disturbed marshes (Haworth, 2002). Waterlogged excavations and wheel ruts were seen to provide ideal conditions for the growth of *A. marina*, both within and bordering saltmarsh communities (see Figure 11). Where ruts extend into the mangrove zone, they may also assist the transportation of mangrove propagules into other areas of the saltmarsh (as seen to occur in runnels created for mosquito control (Breitfuss *et al.* 2003)).

Figure 11: Jump (right) and waterlogged excavation - note the presence of young mangroves in and around the excavation.

Track ruts also appeared to be important sites for the germination of *S. quinqueflora* seedlings. Whilst seedlings were found in great abundance within some ruts, there was little evidence of successful establishment, suggesting either that conditions were not conducive to further development of the seedlings or that subsequent track usage eliminated them.

The formation of algal mats, primarily along track areas of the lower marsh is of importance. Although saltmarsh algae have received little study, they have been noted to colonise areas where the cover of higher plants has declined (Adam 1990). These mats reduce the erodibility of soils in otherwise bare tracks and are likely to prevent the expansion of ruts by hydrological forces.

Saltmarsh soils are particularly susceptible to structural alteration as a result of vehicle passage. Measures of bulk density and penetrability both showed compaction to significantly increase, especially in sandy and loamy soils. This may be of particular ecological importance, as the majority of saltmarsh soils along the Georges River are of these types.

While the dominant plants *S. quinqueflora* and *J. kraussii* were found growing in sandy soils with bulk densities up to 1.47gcm^{-3} and 1.38gcm^{-3} respectively, the majority of soil samples taken from track areas had lower densities than these. This would indicate that plant growth in most track areas should not be adversely affected by soil compaction. However, some track samples (from both low and high disturbance areas) had densities in excess of 1.60gcm^{-3} - the maximum density at which plant root growth has been shown to occur in terrestrial soils (Russell 1973, cited in Liddle 1997). Therefore, soil compaction increases are unlikely to limit the growth of the dominant saltmarsh plants in all but the most compacted track areas.

Although measures of bulk density and soil penetrability are closely related, varying results offered between the two can be expected. Liddle (1975) notes that penetration measures are particularly susceptible to variations in plant litter and soil water content. In saltmarshes, these factors, combined with algal mats and salt crusts are the most likely sources of variation between the two measures of soil compaction.

Soil conductivity, which gives an indication of salinity levels, was the only soil characteristic measured which did not show any overall differences according to track density. However, it should be noted that sampling occurred late in winter, whilst hypersaline condition are most likely to occur late in summer.

Soil moisture was higher in the *Juncus* than *Sarcocornia* communities, primarily due to the overriding water capacity of the peat substrate of the Still Ck *Juncus* community. Nevertheless, there were significant differences according to the treatment factor in both community types and according to the most common substrate types. Mean moisture content of peat was 16.22% (of the control value) less in the high track areas, while in sandy soils the comparative reduction was much greater at 41.50%. Chappell *et al.* (1971) recorded a similar reduction of 46.15% in heavily trampled clay soils of a terrestrial grassland ecosystem, while Payne (1983) found a slighter, yet significant, reduction of 7.69% caused by 8 and 32 passes of an ORV on clay loam soils of a rangeland ecosystem. These comparisons show that sandy saltmarsh soils have a considerably high capacity to dry out with continued vehicle use. However, as the wilting point of sandy soils is very low (1.8% water – Salter & Williams 1965, cited in Liddle 1997) it is unlikely that these reductions in moisture content will adversely affect plant growth in saltmarshes.

Changes to soil moisture has far greater consequences for invertebrate populations, with differences in snail response between the two *Juncus* communities being best explained by the drying of soils associated with high track usage. Roach and Lim (2000) observed that the saltmarsh gastropod *Salinator solida* tended to cluster around vegetation and in small depressions when saltmarsh substrate dried. This behaviour may account for the higher abundance of gastropods in waterlogged depressions rather than dried edges of some tracks. More importantly though it suggests that snails would preferentially relocate to more moist and vegetated non-track areas. This was seen to be the case, especially in *Sarcocornia* communities where track areas are more exposed.

Grapsid crabs showed a clear decline in their distribution with increases in track density. Both direct (contact and burrow collapse) and indirect (habitat modifications) impacts are likely causes of this stark decline. Wolcott and Wolcott (1984) showed that up to 98% of the ghost crab (*Ocypode quadrata*) populations could be directly crushed by 100 passes of 4WDs on an open beach. However, they also found that burrows of 5cm depth offered total protection from crushing, which has several implications for saltmarsh crabs. Firstly, grapsid crabs generally retreat into nearby burrows when disturbed, where they are likely to be protected. However, many were observed to only retreat into the top 1-2cm of the burrow entrance where they may still be crushed. The presence of a few crushed exoskeletons in track areas also suggests not all are able to avoid fast moving vehicles. More generally however, crab populations are likely to be adversely impacted by habitat changes associated with track use, namely reduced vegetation cover (again, more so in *Sarcocornia* communities) and compaction of soils in track areas.

Community and Site Effects

Although the type of vehicle use varied between sites, it was rarely responsible for major differences between track density ‘treatments’. This is largely because this study focused on the density of tracks rather than quantifications of passes. Also, observation suggested that while trail bikes would do greater damage in a single pass than BMXs and mountain bikes, the latter were more likely to follow previous tracks and would therefore do similar damage with repeated passes. Instead, the major differences in track level response between communities are best explained by levels of site usage. Mill Ck and Still Ck 2, which generally showed the least response in track areas, have not, until recently experienced high vehicle usage. As a result many of the track areas sampled - both of high and low density - are likely to have received fewer passes than corresponding areas of other marshes. Observations suggest the *Sarcocornia* communities of Still Ck 1 and Sylvania Waters 1 receive the most regular use, explaining the prominence of heavily damaged, high track density areas at these locations as well as the declines in plant cover and mollusc abundances up to 2-5m from track areas.

Sarcocornia and *Juncus* communities showed a considerable number of differences in their responses to track density, mainly less significant reductions (or even increases) of invertebrate populations and slighter soil compaction within track areas of *Juncus* than *Sarcocornia*. The differences shown between these community types can be explained by a number of factors. Firstly, *Juncus* sites were observed to generally receive less use, probably owing to the taller and spiky nature of the dominant vegetation. Secondly, as only two *Juncus* communities were studied (with each having considerably different substrates) statistical tests were far less powerful and differences less likely to be ‘significant’. However, there may also be several ecological reasons for the differences between the communities’ responses. *Juncus* communities generally consist of more closed vegetation stands than those dominated by *S. quinqueflora*. As a result track areas within the *Juncus* still receive shade and protection from the tall, surrounding vegetation. This, and the protection offered by trampled culms of *J. kraussii*, may explain why the invertebrate populations studied were not reduced in track areas within *Juncus* stands as they were in *Sarcocornia* communities.

Management Recommendations

Due to the endangered status of saltmarshes and their vulnerability to disturbance, immediate measures should be taken to deter the unauthorised use of vehicles in these ecosystems. Access ways (such as fire trails and tracks) to saltmarshes should be fitted with *appropriate* gates and fences. Educational and cautionary signage should be erected to make users aware of the ecological importance of saltmarshes and the legal implications of unauthorised vehicle use. Such measures should be regularly maintained they are likely to be subject to vandalism.

In New South Wales vehicle users who damage a saltmarsh may be liable to prosecution under the *Threatened Species Conservation Act (1995)* and may be fined up to $550 for illegal use of trails under the *Recreational Vehicles Act 1983*. Trail bike units exist within the NSW police force, which may be utilised to implement the above laws and deter further unauthorised use.

As it has been recognised that natural regeneration of saltmarsh vegetation after anthropogenic damage may not always be possible (Laegdsgaard 2002), transplantation from cuttings may be considered as a restoration technique. Burchett *et al.* (1999) showed the transplantation of several species including *S. quinqueflora* and *Sporobolus virginicus* to be a viable, although slow, means of saltmarsh rehabilitation. Restoration may first require the infilling of excavations and ruts, while compacted track soils may need to be excavated and re-levelled to allow for successful recolonisation by vegetation and fauna. Also, the planting of thick *Juncus kraussii* stands and tall *Casuarina glauca* trees across strategic areas (such as track entrance points and around marsh edges) may help to deter future vehicle use.

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